Are Peridotite Xenoliths a Good Record of the Water Content of the Upper Mantle?

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INTRODUCTION.

Small amounts (< 0.005 wt%) of H in nominally anhydrous minerals (NAMs) such as olivine greatly affect the melting temperature, transport properties, and rheological behaviour of the mantle (e.g., Keppler and Smyth, 2006; Hirschman, 2006; Costa and Chakraborty, 2008). Despite this major role of H it is still unclear how much H do in fact NAMs contain in the upper mantle. Direct information comes from crystals in peridotite xenoliths or megacrysts found in alkali basalts and kimberlites. The H content of the olivine from these magmas is highly variable from about <1 ppm to ca. 400 ppm H_2O (Keppler and Smyth, 2006). This could reflect the water contents of the upper mantle from different tectonic settings but several observations complicate such a straightforward interpretation. For example, Demouchy et al. (2006) report zoning in H contents in olivines from mantle xenoliths, with higher concentrations in the crystal centres than in their rims. This suggests that H has diffused out of the crystal during the transport and implies that the xenoliths are a poor record of H content of the upper mantle.

In this communication we discuss the extent to which H content from mantle olivine is lost during transport to the surface. For this, we have constructed a diffusion model of H in olivine that accounts for many aspects of the process of H loss from the crystal and styles of magma transport and degassing.

MATERIALS AND METHODS.

As model parameters we used the fast diffusion mechanism of H in olivine where the extra charge is compensated by a flux of polarons (Kohlstedt and Mackwell, 1998). A new thermodynamic model for the H partitioning between olivine and melt that is pressure dependent and is based on experimental data of Dixon (1997), and Zhao et al. (2004). We assumed that the melt reservoir is infinite with respect to the olivine and that H diffusion in the melt is infinitely fast. This last condition was relaxed for cases of disequilibrium degassing. The diffusion equation was solved by numerical methods (finite differences), taking into account the effects of diffusion anisotropy and multiple dimensions.

Given an initial concentration of H in the olivine, a driving force is imposed by the changing local chemical environment represented in the boundary condition. We modelled three different isothermal melt paths: (1) ascent of a water saturated melt (free fluid present) in equilibrium with its coexisting fluid during all the transport, (2) a water under-saturated melt ascents and reaches fluid saturation at a given depth. It looses water by equilibrium degassing, thus the melt and the fluid are in bulk equilibrium as in path 1, (3) a water under-saturated melt ascents and reaches fluid saturation at a given depth, but volatiles are lost via disequilibrium degassing.

RESULTS AND DISCUSSION.

The type of profiles and amount of H lost from the olivine strongly depends on the ascent path and crystal size. The main results and implications of the modelling can be summarized in the following points:

(1) Homogenous H profiles can be easily produced if the ascent rates are not very high (e.g., 0.1 ms^{-1} for a 2 cm crystal). This means that unzoned natural crystals can not be taken as evidence for the olivines preserving the original source mantle H content.

(2) using olivine grain sizes (1 cm and 10 cm) and source depths (ca 150 km) displayed and estimated from kimberlites, we find that it would require minimum ascent rates of 3 to 300 ms^{-1} to preserve the original H content. These values are among those estimated by other authors with other methods (e.g., Kelley and Wartho, 2000), and strongly argue in favour of megacrystic olivines form kimberlites as being a good record of their H in their sources.

(3) Crystals on the order of a millimeter will not preserve their original water content since this would require ascent rates > 100 ms^{-1}. This is in accord with the zoned crystals of Demouchy et al. (2006).

(4) To fully resolve these issues more data on the H content (including core to rim profiles) is needed from natural crystals. Modelling of multiple crystals with different grain sizes should allow determining the depth, transport rates and original water content of the xenoliths, and thus of the upper mantle.

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